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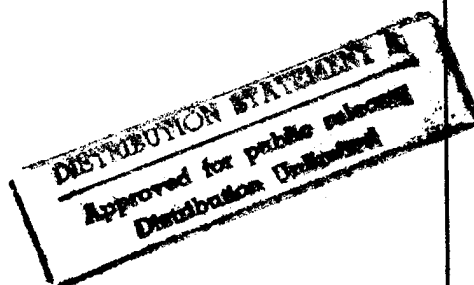
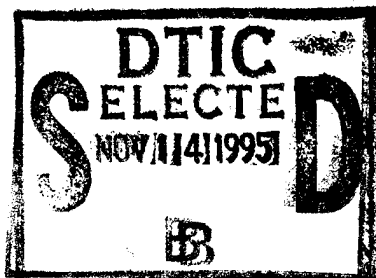
BDX-613-2406

## Fabrication of a Kevlar Liner Assembly

By A. H. Schloman

Published July 1980

Topical Report  
G. W. Edman, Project Leader



DEPARTMENT OF DEFENSE  
PLASTICS TECHNICAL EVALUATION CENTER  
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LINER ASSEMBLY

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G. W. Edman, Project Leader

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**Kansas City  
Division**

## FABRICATION OF A KEVLAR LINER ASSEMBLY

BDX-613-2406, Topical Report, Published July 1980

Prepared by A. H. Schloman

Several liner assemblies were fabricated with Kevlar 49 and epoxy using various wet layup and prepreg processes. A production process, using prepreg material, was developed for fabricating the liner and a wet layup molding process was used to fabricate the Kevlar hat-shaped tunnels. Fabrication of the tunnels using Kevlar prepreg with an autoclave curing process was evaluated.

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## SUMMARY

The purpose of this project was to develop a production fabrication process for a Kevlar liner assembly. The liner is a cylindrical laminate with an inside diameter of 355.6 mm, a length of 1034 mm, and a wall thickness of 1.2 mm; the liner is made from Kevlar 49 fabric impregnated with epoxy resin.

As originally designed, the liner had an integral mounting flange and a metallized exterior surface. The metallized exterior was deleted, and an injection-molded plastic mounting ring was bonded to the liner to replace the integral flange. Twelve hat-shaped sections added to the outside diameter of the liner eventually were replaced by oval tubular tunnels.

The first liners were fabricated using established wet layup techniques and then machining the outside diameter of the Kevlar liner to the desired wall thickness. This method was not a cost-effective production process. Using wet layup techniques, a method of wrapping and then overwrapping the liner with Mylar and glass roving eliminated the machining requirement. A wet layup method was also used in molding the hat-shaped tunnel sections to produce tunnels with acceptable surface finishes. Because wet layup methods require longer fabrication time than prepreg layups, work was started on fabricating both the liner and tunnels from prepreg material.

A process was developed for wrapping the liner to size using Kevlar prepreg material and a special overwrapping procedure. Several tunnels also were fabricated from prepreg using special tooling and an autoclave curing cycle, but further development will be required to develop a production process.

Future work will be directed toward developing and evaluating a pultrusion process for fabricating applicable parts, such as the tunnels.

## DISCUSSION

### SCOPE AND PURPOSE

The purpose of this project was to develop a production process for fabricating a liner assembly using Kevlar 49 fabric and epoxy resin.

Various methods have been used to fabricate the liner and tunnel sections, including several wet layup techniques developed to fabricate the liner to size and the process used to fabricate the hat-shaped tunnels. Special fabrication techniques and tooling developed in this project have allowed Kevlar prepreg material to be used as a production process in place of the wet layup methods. All development and fabrication work was done on full size tooling.

### PRIOR WORK

Work has been done at Bendix Kansas City on isostatic molding the cylindrical liner and a liner with integral tunnels because molding could have resulted in a higher-density laminate and in eliminating bonding the hat sections to the liner.

### ACTIVITY

The original liner design required a Kevlar laminate with an inside diameter (ID) of 381.0 mm, a length of 1.068 m and a wall thickness of 1.27 mm. This liner had an integral mounting flange 14.86 mm wide. The outside finish had to be suitable for metalizing and the inside finish had to be smooth.

This design was later changed to include 12 extruded polysulfone tunnels bonded to the liner outside diameter (OD). The integral Kevlar flange was replaced by an injection-molded plastic ring bonded to the ID. The metallized outside surface was deleted, thus changing the OD surface requirements to a condition which allowed good bonding of the tunnels. Several additional minor changes also were made in the size, shape, and material of the tunnels. The tunnels were made of a Kevlar 49 fabric laminate. The final size of the liner was 355.6 mm ID by 1.034 m long, with a wall thickness of 1.27 mm.

#### First Liner Design Fabrication

The first liner design incorporated an integral flange and had a short tapered or flared section near the flange or forward end. Two separate pieces of fabric were needed to lay up the liner

with fabric and to make the flange integral with the cylindrical section. The cylindrical and tapered section required a piece of Kevlar fabric 6.4 m long, and the flange was composed of five strips of fabric 20.32 cm wide, cut on a bias from 127-cm-wide fabric. This material was placed in an oven at 79.4°C for 1.5 hours to remove any moisture.

The liner layup process was started by applying a thin film of mold release to the aluminum layup mandrel (Figure 1). This film was allowed to air dry for several minutes, and then it was wiped off several times. The mandrel then was coated with a thin film of resin.

The resin is dyglycidyl ether bisphenol-A. A small amount of thickener was added to the resin used to coat the layup mandrel.

Immediately after applying the resin film, the Kevlar fabric was removed from the oven and placed on the coated mandrel in a counterclockwise direction with the cut edge of the fabric over the flange radius and up on the flange about 6.5 mm. This first layer of fabric was applied with some tension, and the resin was worked into the material.

After the first layer of fabric was applied, a strip of fabric was applied to the flange and taped in place with Mylar tape while the strips were pulled tightly against the flange and mandrel (Figure 2). The flange strips were inserted between each layer of fabric, and the joints between each strip were staggered. This layup procedure was continued until all five flange strips and the full length of the 127-cm-wide fabric had been used. The completed layup was held in place with Mylar tape wrapped around the part with the sticky side out (Figure 3).

The liner then was rotated while a brush coat of room temperature resin was applied. The resin must not be forced into the fabric, but must be allowed to wick into the fabric naturally. The resin wicks in easier if the part is warmed with a heat gun directed along the axis of the part during rotation.

After the part was impregnated with resin, the layers of fabric were compressed against the mandrel using a glass roving overwrap. The overwrap was a butt wrap, started at the flange end; during wrapping, close attention was given to assure that the circular wraps were placed tightly against the flange. The flange forming ring was added after two layers of roving had been applied to the cylindrical section.

Before installing the flange forming ring, the flange area was brushed with more resin. Then, a two-piece ring was placed around the part against the flange and finger tightened. Eight

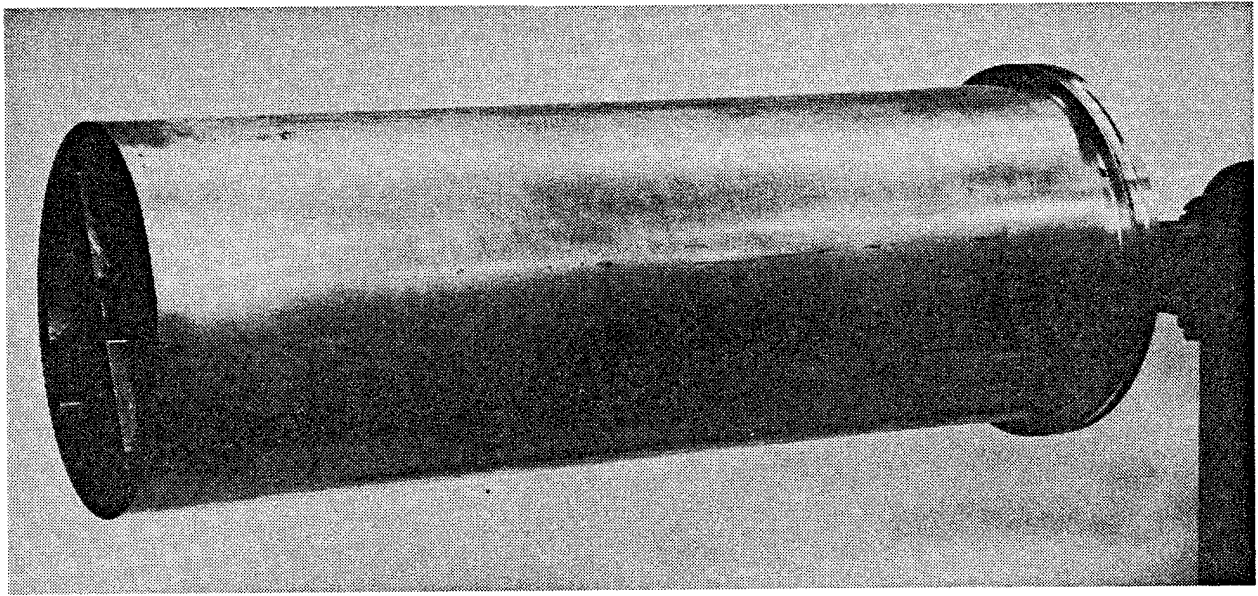


Figure 1. Liner Layup and Machining Mandrel

clamp blocks were installed and finger tightened. The ring and clamp blocks were alternately tightened until the ring was clamped against the flange and against the cylindrical section. Then an aluminum ring was clamped over the material at the other end of the liner. The completed assembly (Figure 4) was placed in a preheated oven at  $93.3^{\circ}\text{C}$  and cured for 2 hours. The part was rotated during this cure. After this initial cure, the liner was cured for an additional 24 hours at  $160^{\circ}\text{C}$ ; it was not rotated during this cure. A view of the cured liner with the glass overwrap is shown in Figure 5.

To obtain the 1.2 mm wall thickness, the OD of the liner had to be machined. The layup mandrel was constructed so that it could be used on the lathe as a machining mandrel. However, the cured liner fit the layup mandrel loosely because the Kevlar has a negative coefficient of thermal expansion. This feature aids in reducing the amount of shrinkage of the laminate during cool down. The loose fit caused some movement of the liner during the machining process, but the liner was held on at one end with clamps. The complete outer surface of the Kevlar liner was machined using a single-point negative rake carbide tool, several holes were added to the flange using spade drills, and a slot was machined in the flange with a special router bit. The machined liner is shown in Figure 6.



Figure 2. Liner Layup Process

After machining, a reflective surface had to be applied to the outside of the liner. Extensive surface preparation, some special tooling, and large size plating equipment were required to plate the reflective surface on the liner. Sputtering was evaluated but did not produce a reflective surface; vapor deposition had similar problems.

To obtain the reflective surface, aluminum foil tape was used. This tape, approximately 91.5 cm wide, had a high temperature contact adhesive. The aluminum foil was applied in two pieces. The largest piece was applied to the cylindrical section, and the second piece was placed on the tapered section. This foil was applied with minimal problems and gave the required reflectivity. A view of the first completed liner with the reflective surface is shown in Figure 7.



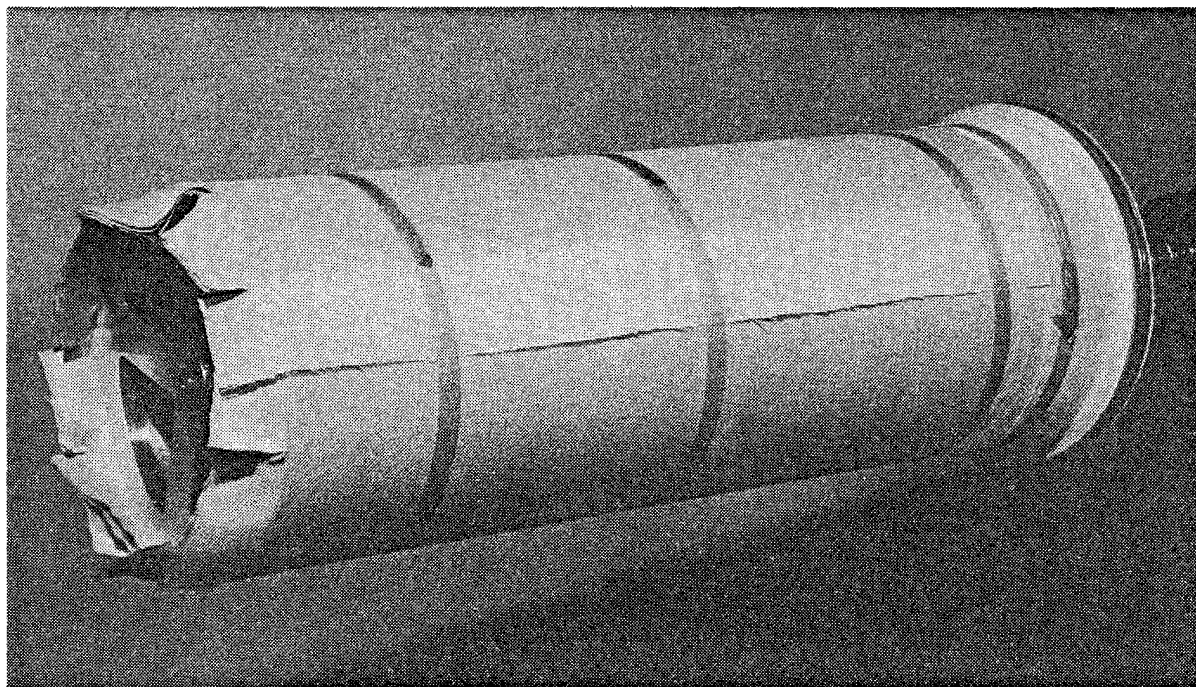


Figure 3. Completed Layup

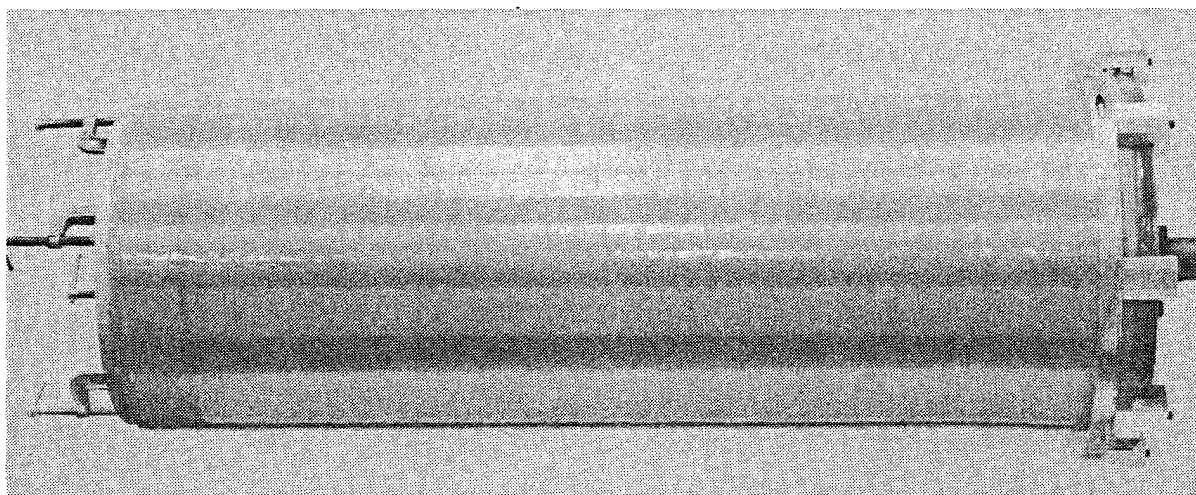


Figure 4. Liner With Fiberglass Overwrap

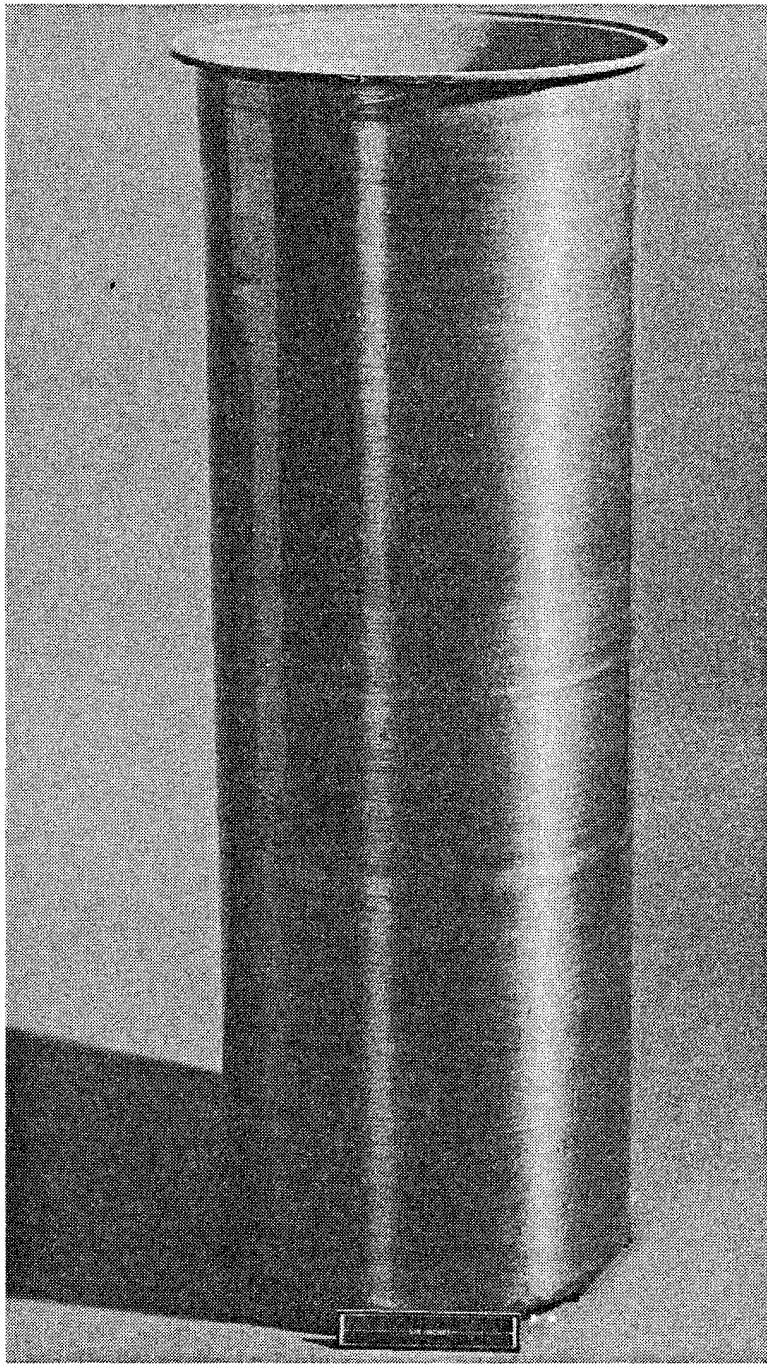


Figure 5. Cured Liner

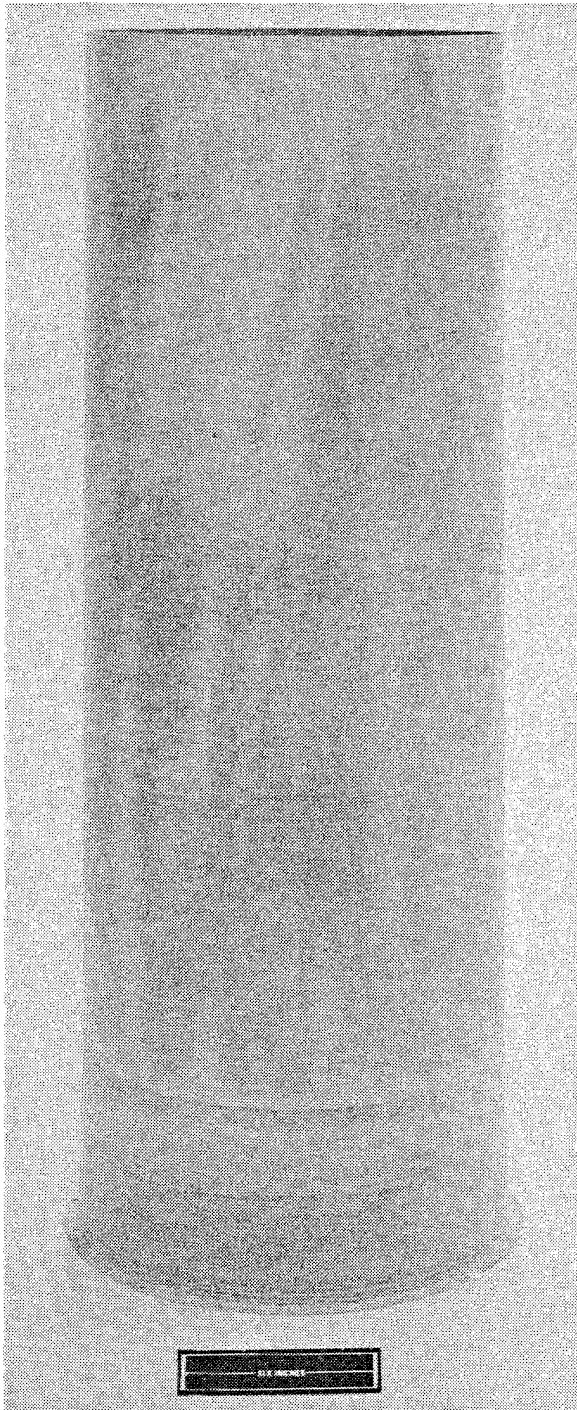


Figure 6. Machined Liner

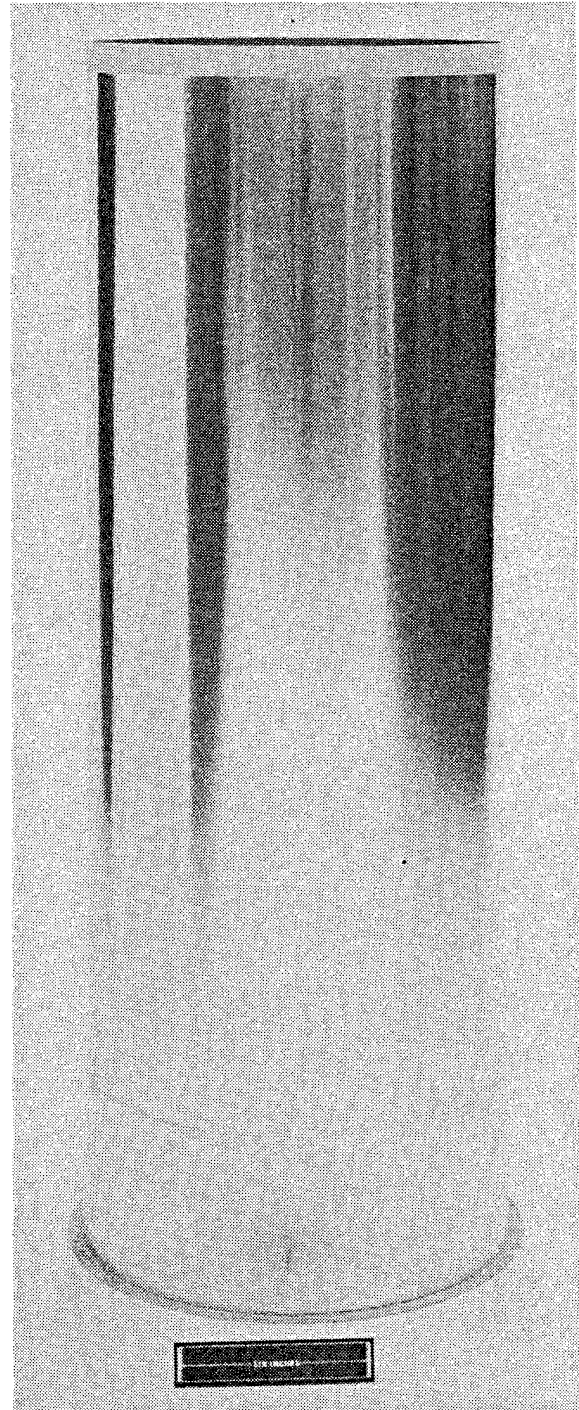


Figure 7. Liner With Reflective Surface

## Second Liner Design Fabrication

The second liner design included a polysulfone flange bonded to one end of the liner and 12 polysulfone tunnels. These tunnels were axially bonded to the liner's outside surface. This liner design required a new aluminum cylindrical layup mandrel. By using dimensional data from the previous liners, the new mandrel was sized so that, at the epoxy cure temperature, the expansion of the aluminum mandrel would produce the correct liner ID. Then, the outside diameter was machined to give the desired wall thickness.

The first Kevlar cylinder for the new liner assembly was fabricated using the same basic layup techniques as the first liner. The polysulfone flange was molded and then machined to fit the ID of the liner. Twelve openings also were machined into the flange to accept the extruded polysulfone tunnels. The flange and the 12 tunnels were bonded to the liner with a film adhesive (Figure 8).

The bonding of the polysulfone flange proved to be successful; however, the long polysulfone tunnels could not be successfully bonded to the liner. The differences in the coefficients of expansion between the polysulfone and the Kevlar are so large that, as the liner assembly cools after bonding, the bond fails at the tunnel interface. Because of this failure, several tunnels fell off, and the tunnels that remained intact had distorted contours.

To establish an acceptably efficient process of producing the liner, the machining of the outside diameter had to be eliminated or greatly reduced. Accurate machining of the outside diameter would require another machining mandrel to fit the ID of the liner because the Kevlar has a negative coefficient of expansion. Thus, as the mandrel cooled down after the cure cycle, it decreased in size while the Kevlar maintained a portion of the original diameter. Also, it was very difficult to obtain a good smooth surface because the tool cut through and into different layers of cloth, producing irregular edges. Therefore, development of the necessary techniques to build the liner to size was initiated. The procedure developed allowed fabrication to size of the ID and wall thickness. This wet layup technique also resulted in the desired inside and outside finish.

The aluminum liner had to be cleaned with ketone and polished with steel wool to remove any material or impressions left from the previous part. Then the mandrel was mold released and allowed to dry several minutes before wiping off the excess and rubbing the mandrel with a soft cloth to obtain a smooth, lightly polished surface. To this surface was applied a thin coating of resin



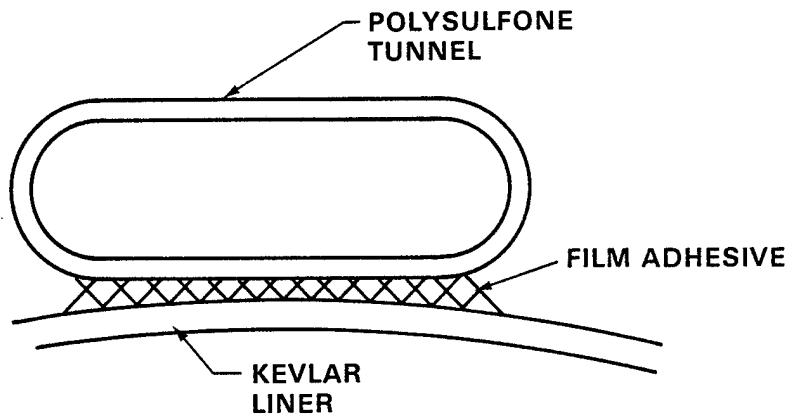


Figure 8. Polysulfone Extruded Tunnel

with thickener added. The resin layer had to be applied uniformly and with the correct thickness to avoid resin bead-up on the mandrel. Application of this layer of resin is shown in Figure 9.

The dried Kevlar cloth then was wrapped around the mandrel (Figure 10). This cloth had to be applied as tightly as possible to eliminate wrinkles in the finished liner. To hold the fabric in place during the application of resin, Mylar tape was wrapped around the liner with the sticky side out (Figure 11).

The room temperature resin was then brushed on and allowed to work into the Kevlar fabric naturally. Forcing the resin into the cloth with a brush or scraper introduces air and voids. The liner was continuously rotated during and after the resin application. Figure 12 shows the technique used to apply and spread the resin over the part.

After the resin impregnated the fabric, 25.4-mm-wide tape was wrapped around the part using a one-half overlap wrap pattern, with about 4540 g of tension on the tape and with the part rotating at about 10 rpm. Note in Figure 13 that the tape was wrapped in the same direction as the fabric to force the fabric tight against the mandrel. Wrapping the glass tape on at low speeds allowed the resin to impregnate each layer. This process causes the layers of fabric to shift and move, thus eliminating wrinkles and giving a higher density composite. After the part was completely wrapped, the Mylar tape was removed, and the liner was wrapped with the Mylar sheet.

The Mylar sheet, about 0.254 mm thick, was placed around the part and allowed to overlap the ends of the part. The slick Mylar surface was placed next to the part and held in place with tape;

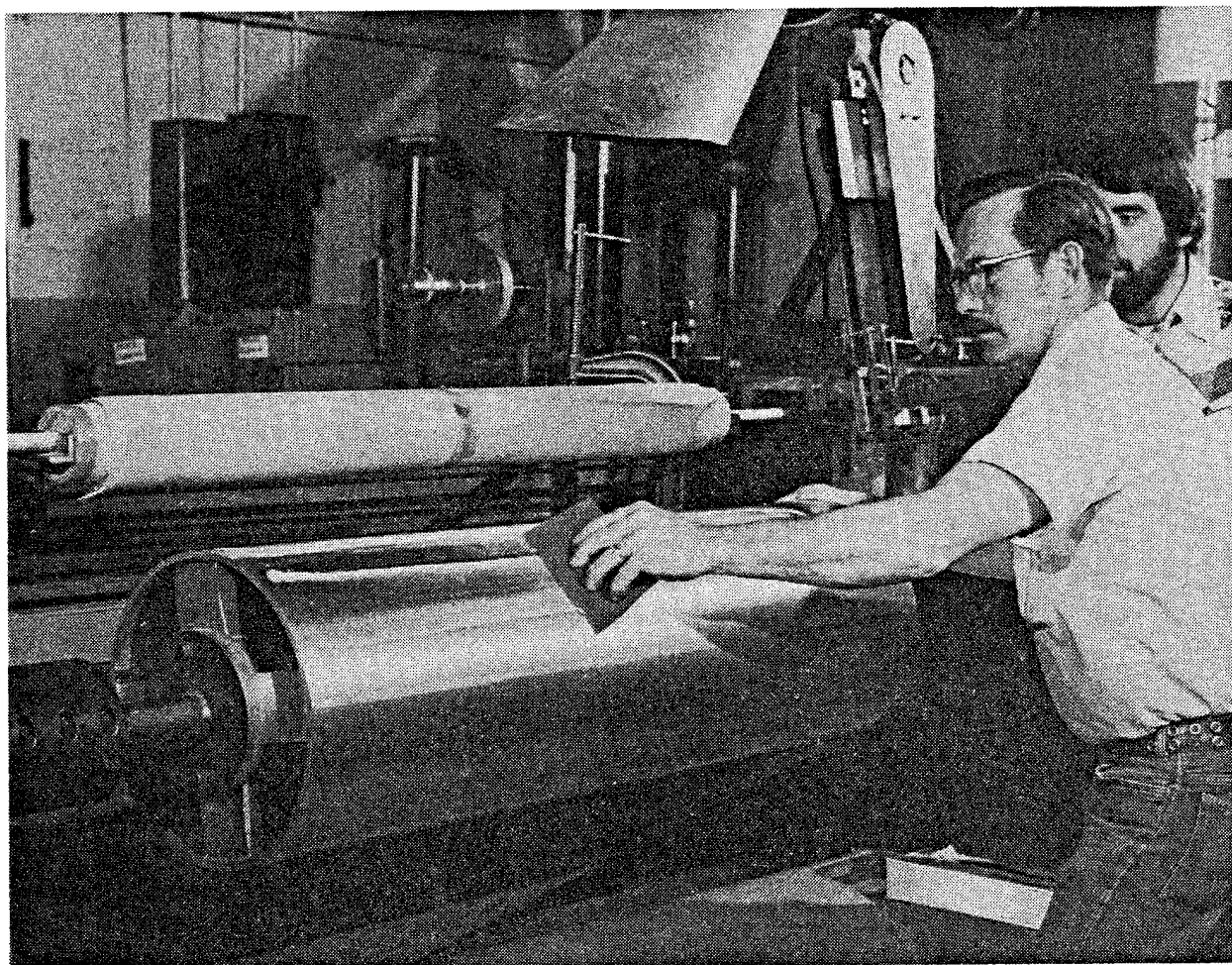


Figure 9. Coating Mandrel With Resin

the sheet then was wrapped around the part in the same direction as the fabric (Figure 14).

The Mylar was overwrapped with 20-end glass roving, using 4558- to 6810-g tension and with 0.66 mm lead (Figure 15). This overwrap further compressed the fabric to the desired thickness and forced out any excess resin. Wrapping speed was critical on this operation; speeds below 7 rpm produced the best parts. The overwrap was started and stopped about 6 mm from the ends to keep the liner from being locked on the mandrel with the fiberglass overwrap after curing.

The liner was placed in the B-stage oven and rotated during part of the cure cycle. A view of the oven, cart, and liner is shown in Figure 16. The cure cycle consisted of 2 hours at 93.3°C with the part rotating, followed by 24 hours at 160°C without rotation.

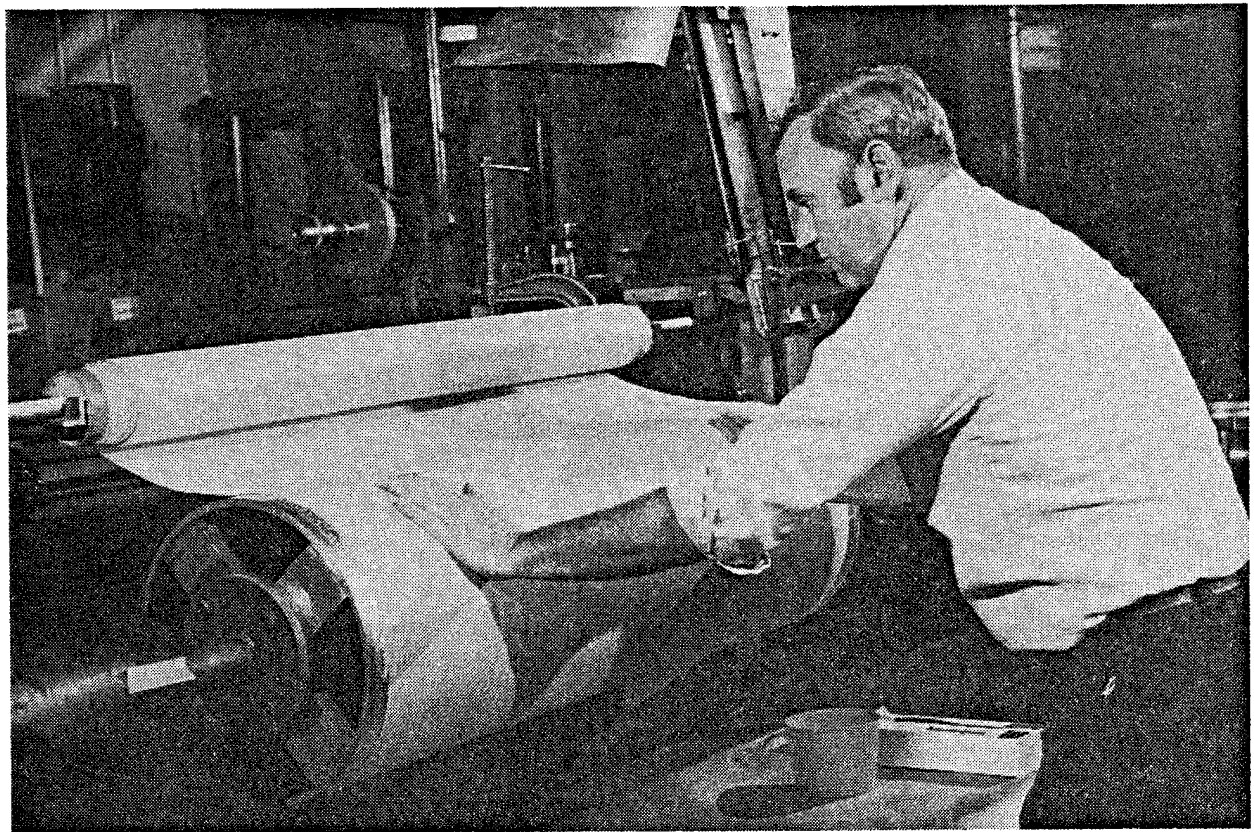


Figure 10. Layup of Dry Fabric

After cooling, the fiberglass overwrap was cut at the Mylar overlap point, and the excess flashing was removed. Then the Mylar and overwrap were removed (Figure 17). The Mylar sheet produced an acceptable surface finish, with the ID molded to size. The only operation required to complete the liner was to cut it to length. Figure 18 shows a liner being removed from the mandrel and illustrates the type of surfaces obtained by this fabrication method.

#### Hat Section Fabrication

To replace the polysulfone tunnels, Kevlar hat-shaped sections, (Figure 19) were molded and bonded to the liner. These hat sections were made with a wet layup, using the same Kevlar material and resin as the liner, and then molded to shape.

Five layers of Kevlar material, 152.4-mm wide and approximately 1000-mm long, were placed in a tray and brush coated with resin. After the layup was thoroughly impregnated, it was placed on an

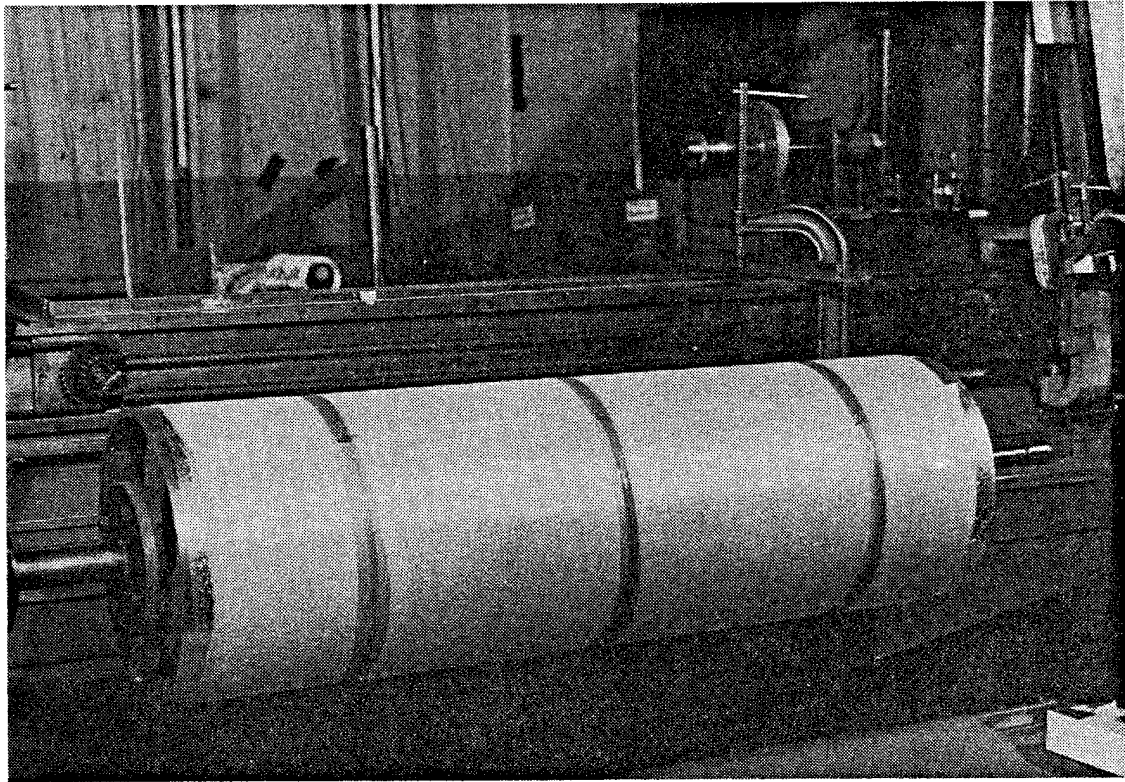


Figure 11. Completed Fabric Layup

aluminum plate and transferred to the press. The heated aluminum mold was brushed coated with resin, and the layup was placed on the bottom section of the mold (Figure 20). The mold was closed, and the excess resin was allowed to runout during the cure. The same cure cycle as the liner was used for the hat section. Figure 21 shows the as-molded condition of the hat section. The sections were then cut to size and length (Figure 22). This fabrication method produced good inside and outside surface finishes that were necessary to reduce damage to the cables and lines. These hat sections and the polysulfone ring then were bonded to the liner with a film adhesive; metal nut plates were riveted to the OD of the liner at the other end to complete the assembly (Figure 23).

#### Liner Fabrication With Prepreg

Because Kevlar prepreg is easier to use in production than a wet layup process, several liners were fabricated with prepreg. The first prepreg liner was fabricated by wrapping six layers of



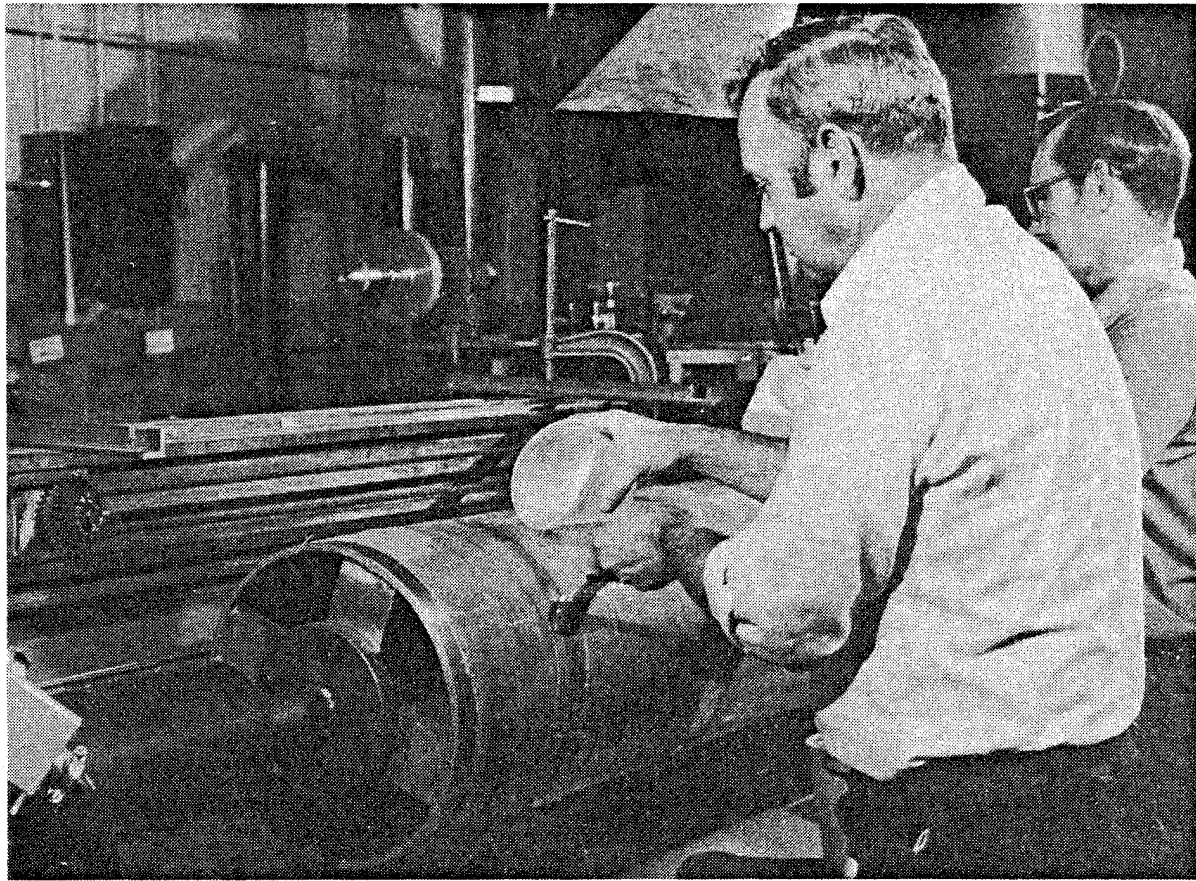


Figure 12. Applying Resin to Fabric

prepreg around the mandrel and then applying the Mylar sheet over the outside surface. This Mylar sheet was then overwrapped with glass roving and cured at  $132^{\circ}\text{C}$  for 4 hours. When removed from the layup mandrel however, the liner had a poor inside surface finish.

To improve the inside finish, another group of liners were fabricated using a sheet of thin Mylar which was wrapped around the mandrel. The prepreg cloth was then wrapped over this Mylar, and the outer surface of the prepreg was wrapped with a sheet of Mylar. Then, the unit was overwrapped with 20-end fiberglass roving. This method did not improve the inside surface finish.

Previous experience with the wet layup liner indicated that, to obtain a good surface finish, the laminate has to retain as much resin as possible, and, to keep the resin in the layup, the edges of the layup had to be enclosed. Several methods were evaluated,

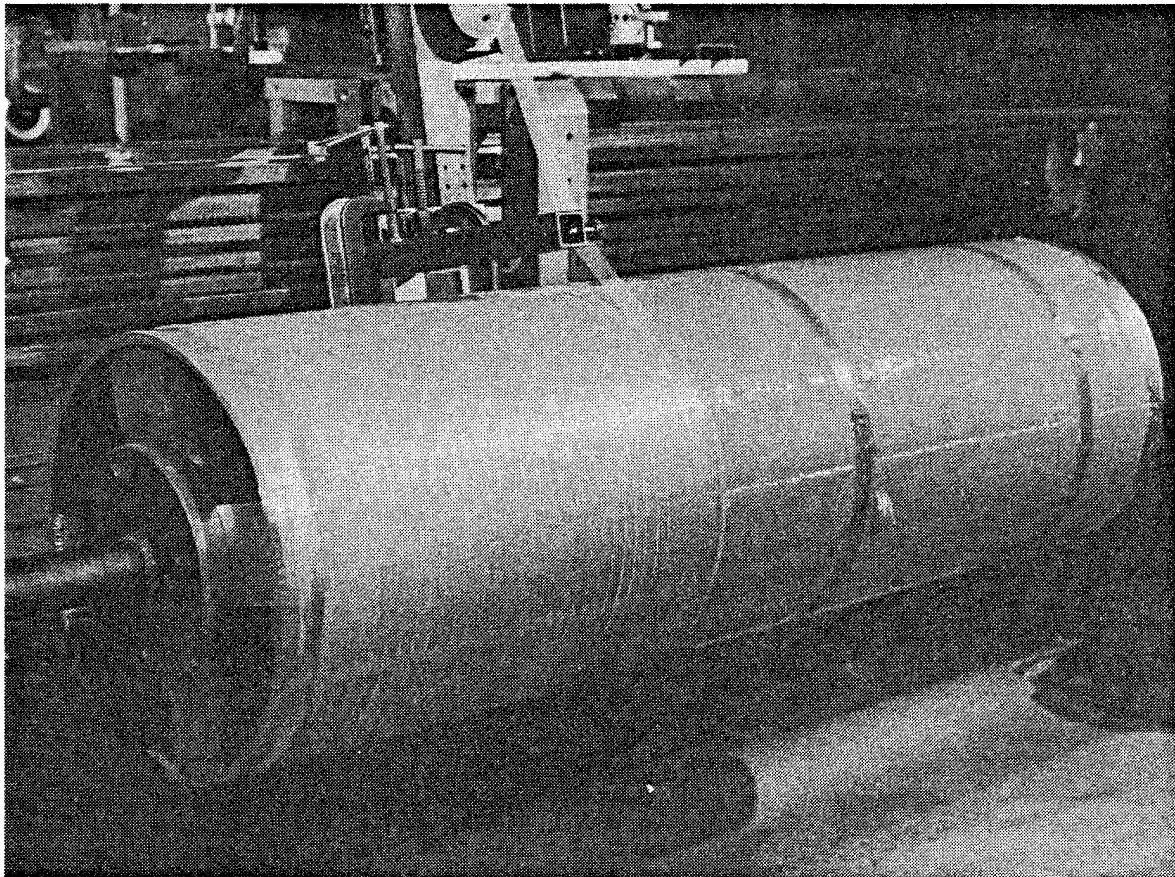


Figure 13. Mylar Tape Overwrap

and one proved to be most effective. A strip of silicone rubber about 25-mm wide was placed around the mandrel at both ends, with one edge of the strip against the prepreg layup, and the Mylar sheet that is placed over the layup was lengthened so that it covered both rubber strips.

The glass overwrap was started on the outside edge of the rubber strip and extended across the layup and over the other rubber strip. This process successfully sealed off both ends of the prepreg layup and held most of the resin. This processing method gave an acceptable inside surface finish and several liners were fabricated using this method. A close-up view of this sealing technique is shown in Figure 24.

#### Tunnel Fabrication With Prepreg

The Kevlar layups were easily removed from straight aluminum mandrels because of their coefficient of thermal expansion. Therefore,

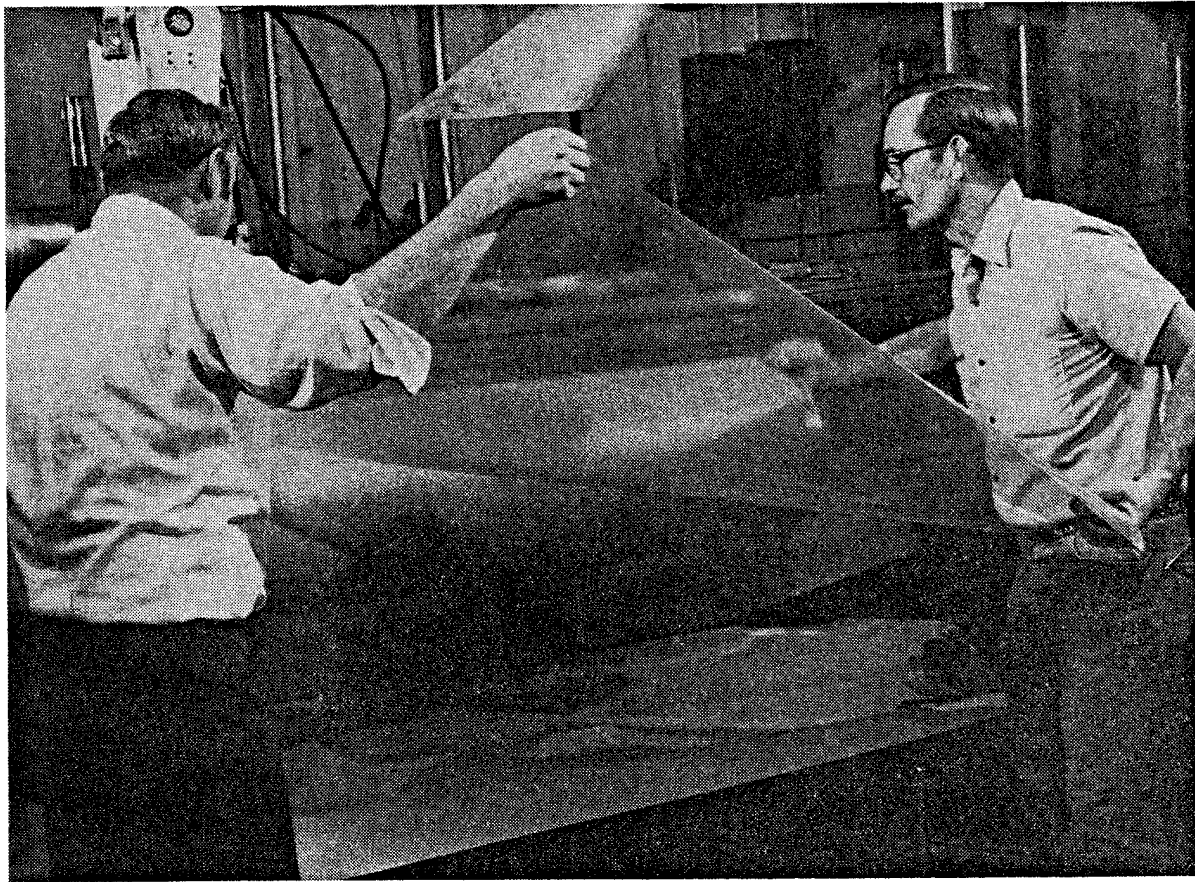


Figure 14. Applying Mylar Cover Sheet

layup of a full-length tunnel using Kevlar prepreg was attempted. An aluminum mandrel with the same dimensions as the inside of the polysulfone tunnel was fabricated. The mandrel surface was highly polished, and a vacuum hole was added to one end. The prepreg was wrapped around the mandrel in one continuous strip which was long enough to give five-layer coverage. During the wrapping operation, the mandrel was held in a wrapping machine; the prepreg was pulled tight against the mandrel by hand, and all the wrinkles were pressed out of each layer. Then the part was overwrapped with 25-mm-wide Mylar tape to debulk the laminate (Figure 25). After debulking, the Mylar tape was removed, and the part was bagged for the autoclave curing process.

The tunnel was bagged in a special 3.2-mm-thick silicone rubber tube about 37 mm in diameter by 1080 mm long. The tube was fabricated by bonding the edges together with a silicone adhesive. The tube was placed inside a larger diameter aluminum tube, and

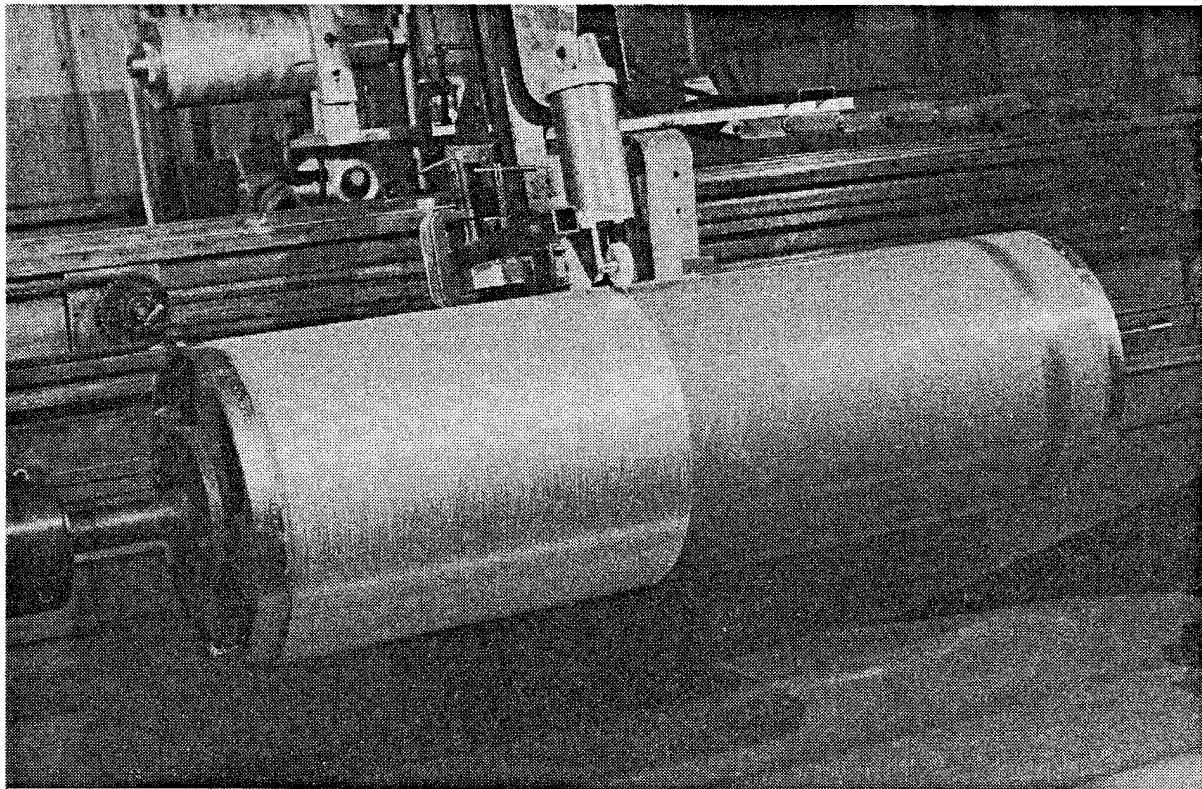


Figure 15. Applying Roving Overwrap

the rubber was folded back over the outside of the metal tube at both ends. A vacuum then was applied between the silicone tube and the aluminum tube, which forced the rubber outward and against the inside surface of the metal tube. With the vacuum applied, the tunnel was inserted in the tube (Figure 26). When the vacuum was released, the silicone rubber tube collapsed around the laminate. The ends of the bladder were rolled off the aluminum tubing and sealed to the mandrel. This silicone bladder fit tightly around the laminate and produced a smooth finish because no bleeder cloth was used between the laminate and bladder. A view of the prepreg tunnel laminate fabricated with this method is shown in Figure 27.

#### ACCOMPLISHMENTS

Special processing techniques were developed and refined that allowed the Kevlar liner to be fabricated using either prepreg or a wet layup process. These process techniques allowed close control of the liner wall thickness and produced an acceptable finish on the inside surface. The outside surface was adequate for bonding on the 12 hat sections or tunnels.



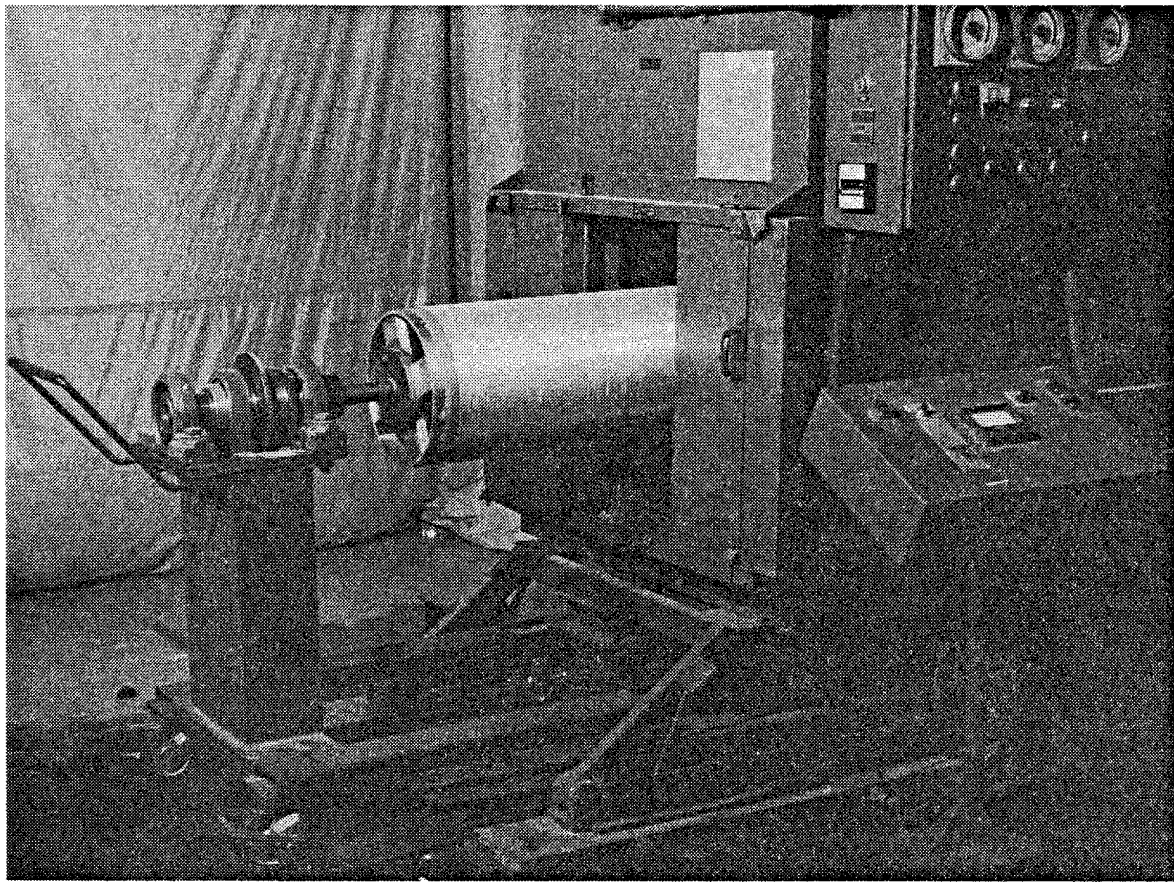


Figure 16. B-Stage Oven

Using Kevlar prepreg and some special tooling, several Kevlar tunnels were fabricated using an autoclave cure cycle. These tunnels demonstrated that the process would produce a tunnel with a uniform cross section and also meet the requirement that the inside surface of the tunnel or hat section be smooth.

Molding the hat sections was accomplished by using matched-metal molds. A wet layup process combined with special resin treatment on the surface of the molds produced parts with the required uniform wall thickness and a smooth inside surface finish.

The hat sections were bonded to the exterior of the liner with a film adhesive, but several of the hat sections developed bond line failure which could be attributed either to surface preparation or to the need for a more flexible adhesive.

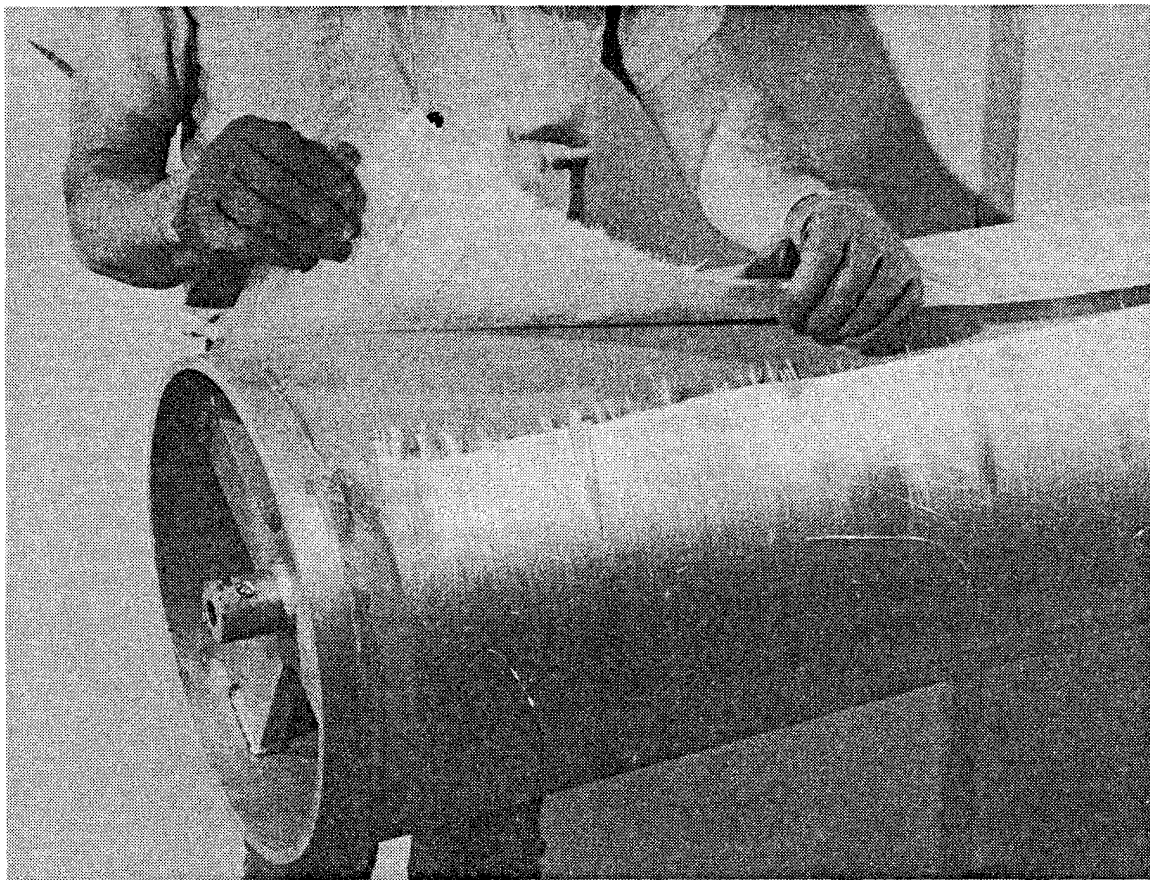


Figure 17. Removing Overwrap and Mylar Sheet

#### FUTURE WORK

No future fabrication or development work on this liner assembly is planned unless this Kevlar component is included in new system designs. A contract has been negotiated for determining the feasibility of pultruding Kevlar components similar to the tunnel.

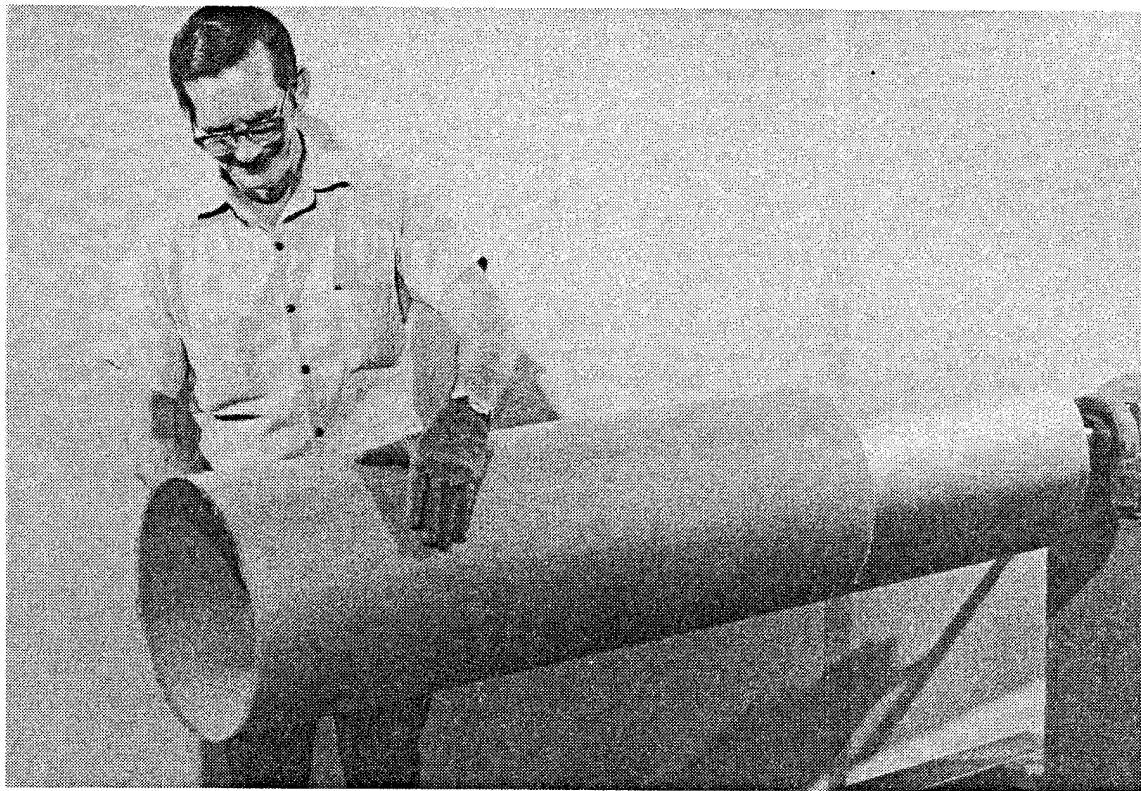


Figure 18. Removing Liner From Mandrel

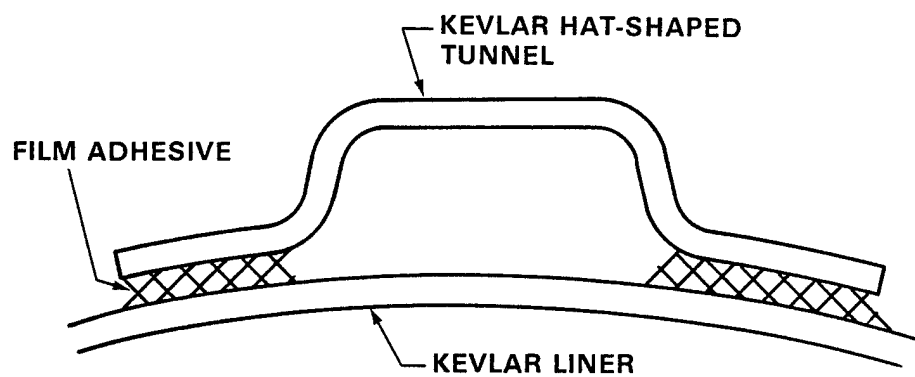


Figure 19. Kevlar Hat-Shaped Tunnel

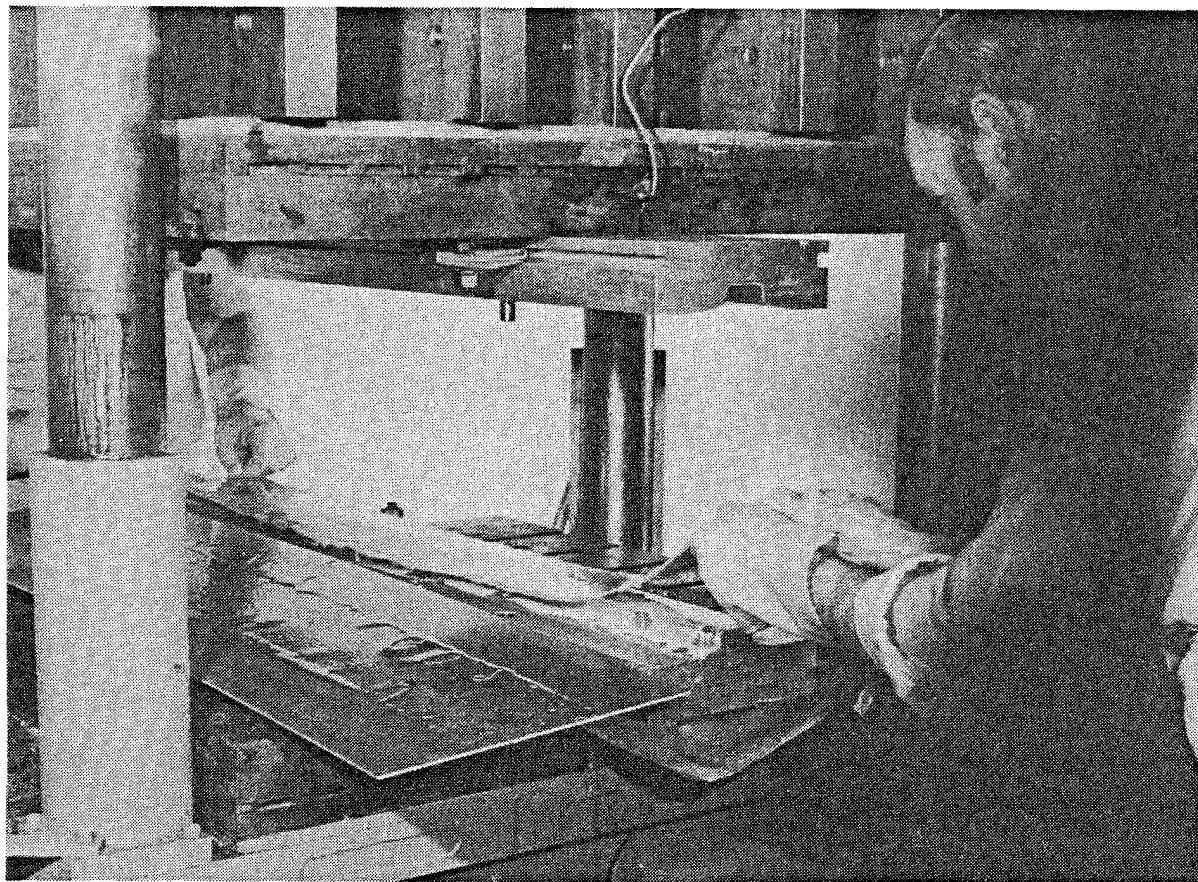


Figure 20. Wet Layup of Kevlar Hat Sections



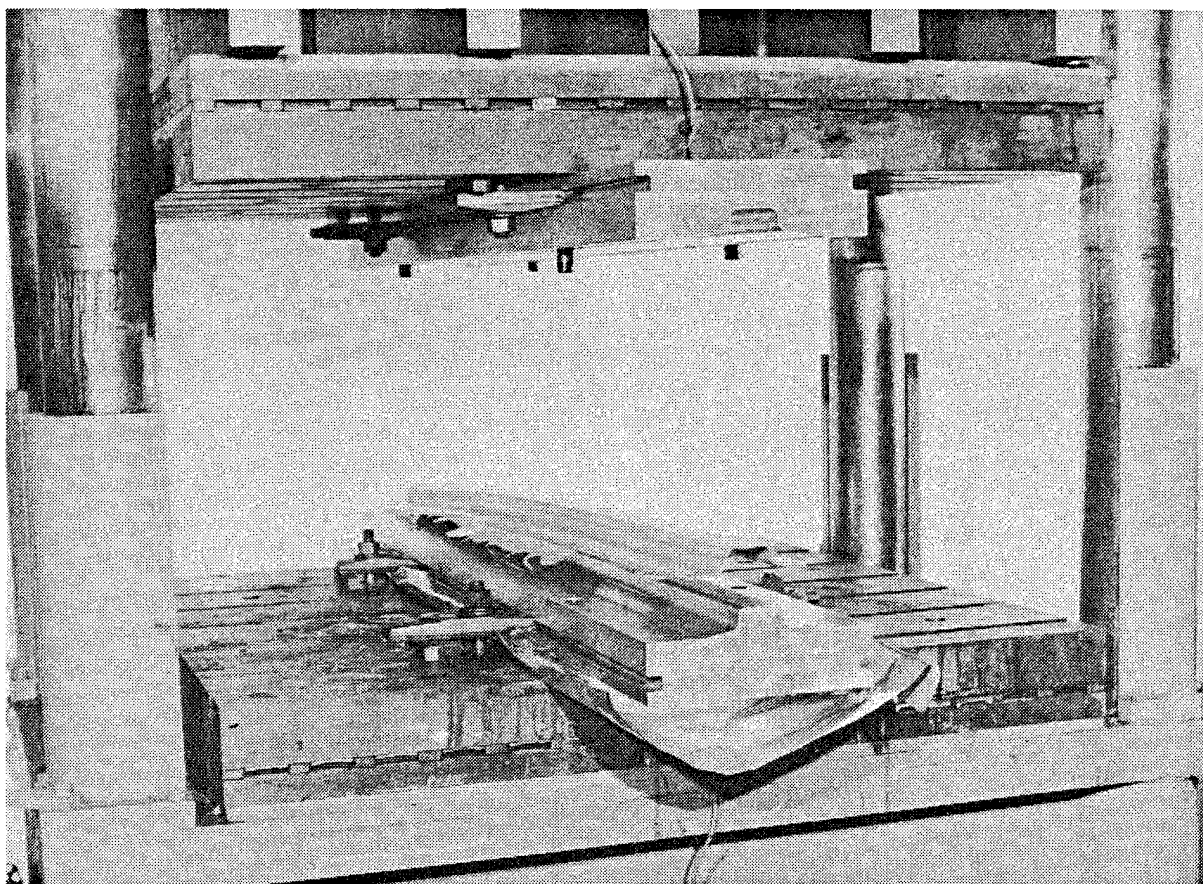


Figure 21. Molded Hat Section

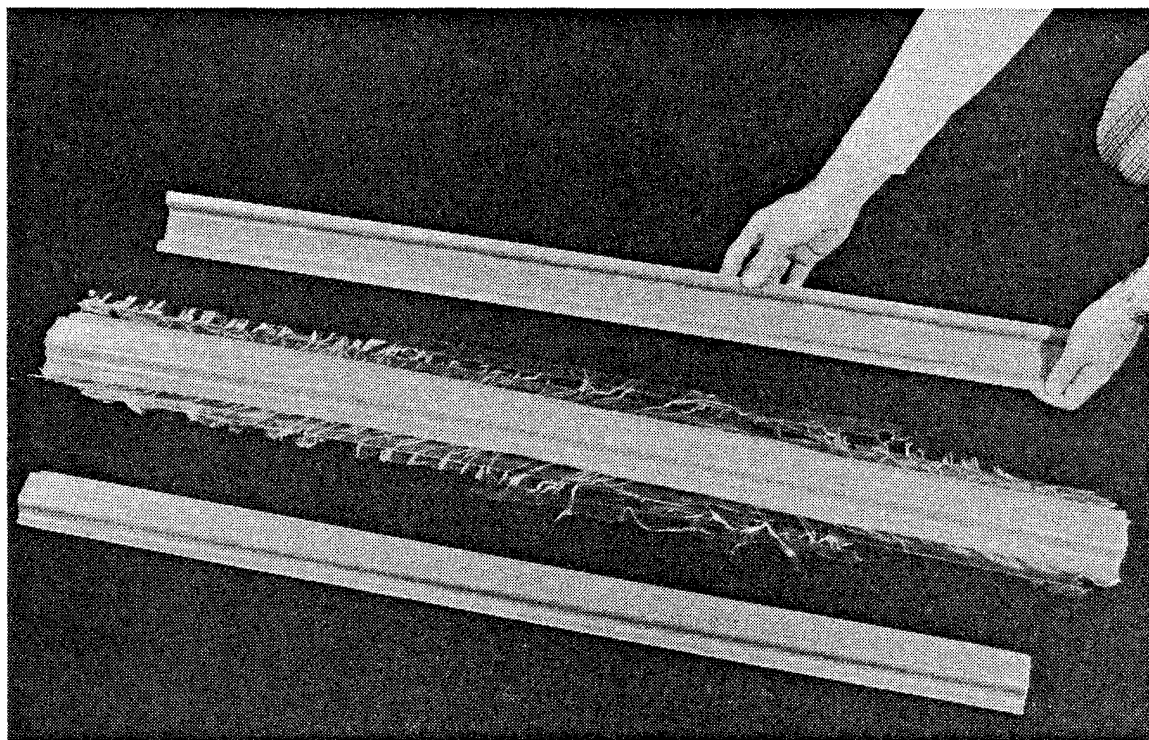


Figure 22. Completed Kevlar Hat Sections

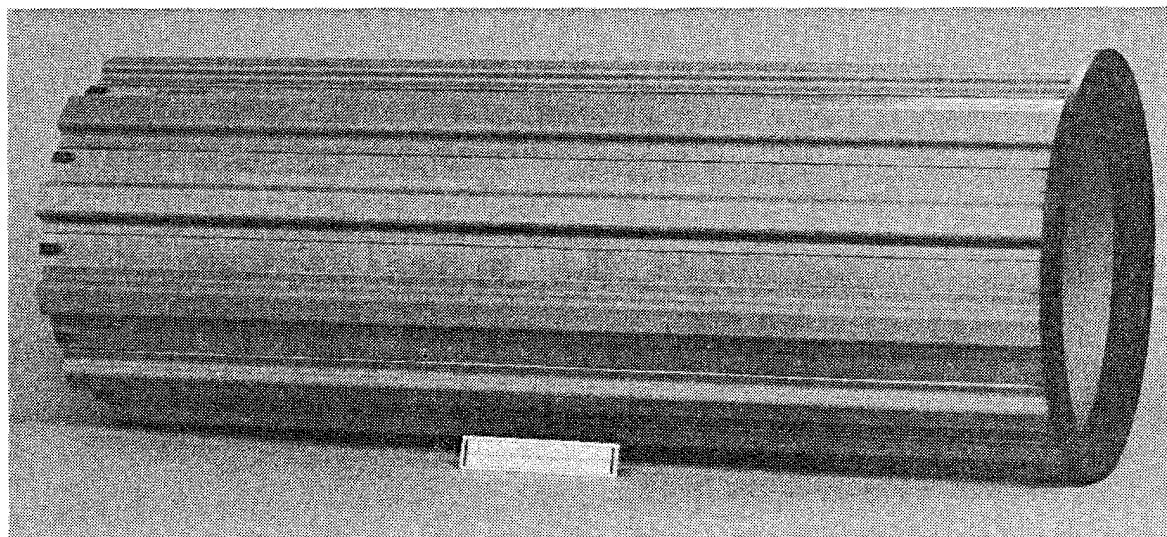


Figure 23. Complete Liner Assembly

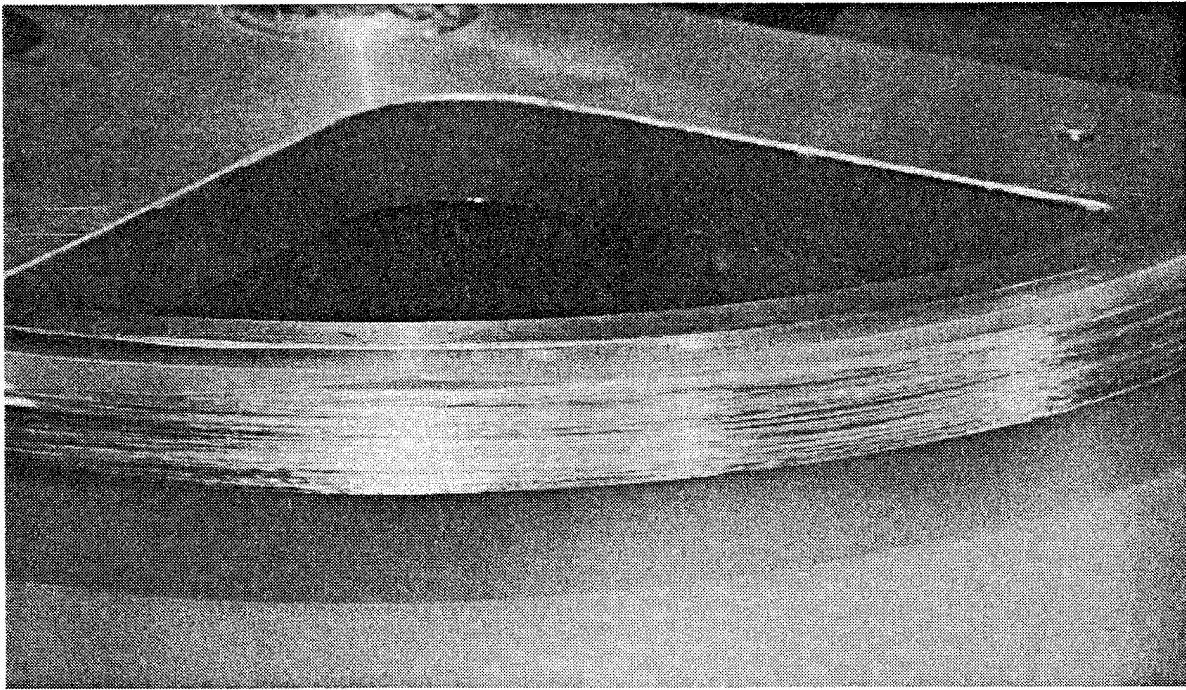


Figure 24. Sealing Edge of Prepreg Layup

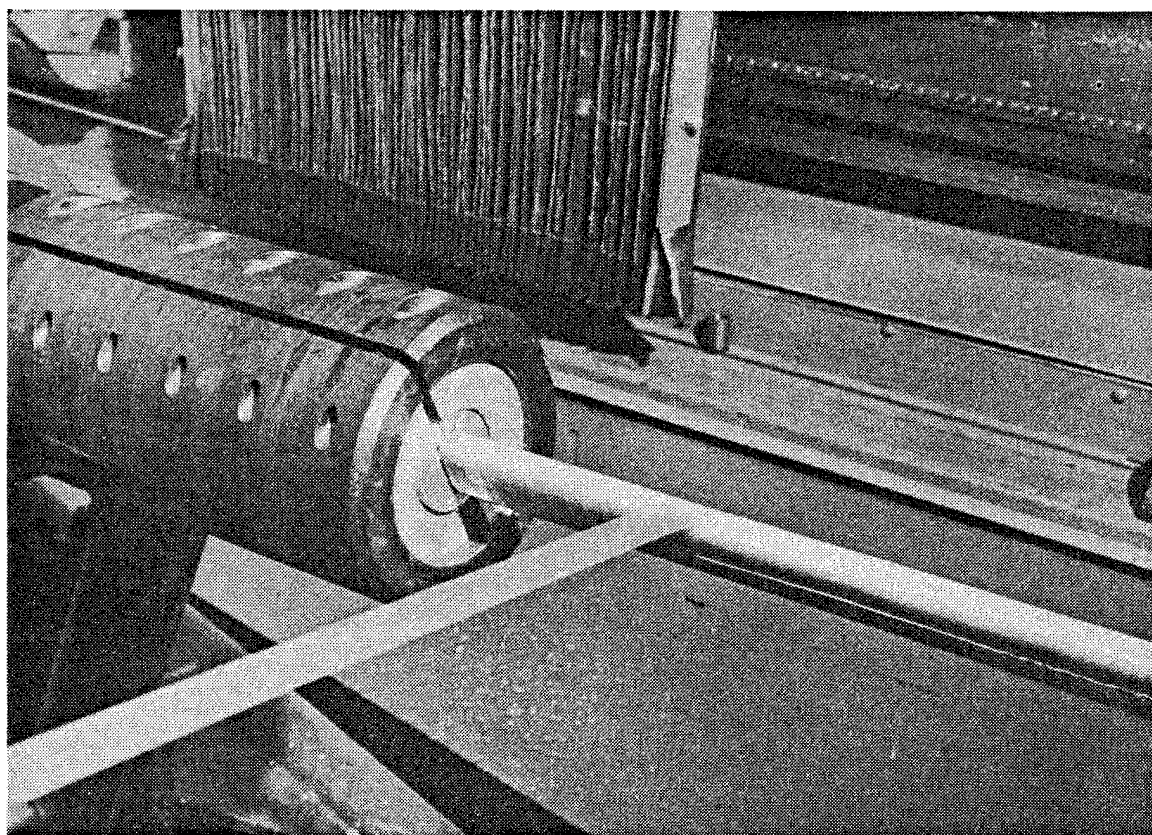


Figure 25. Overwrapping Prepreg Tunnel



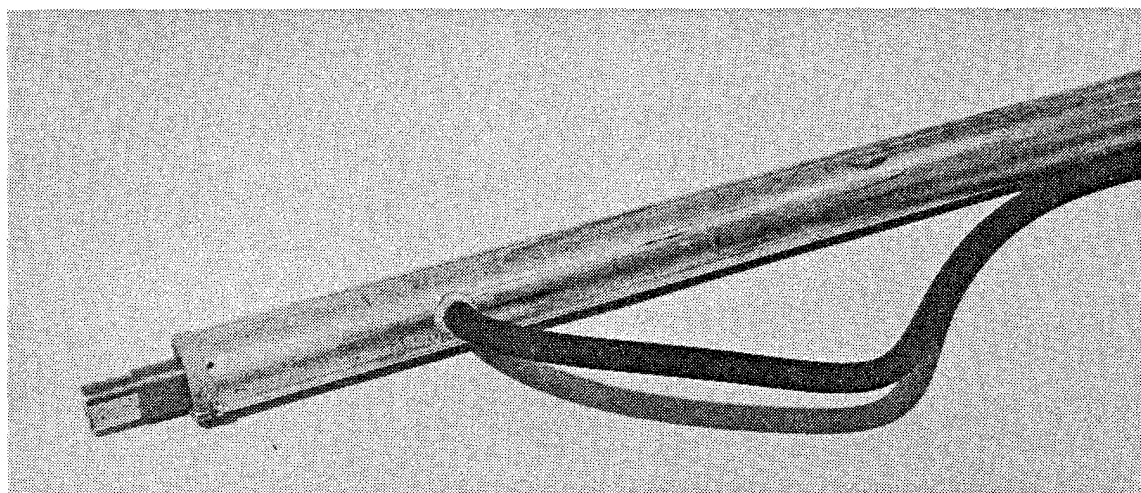


Figure 26. Tunnel Autoclave Tooling

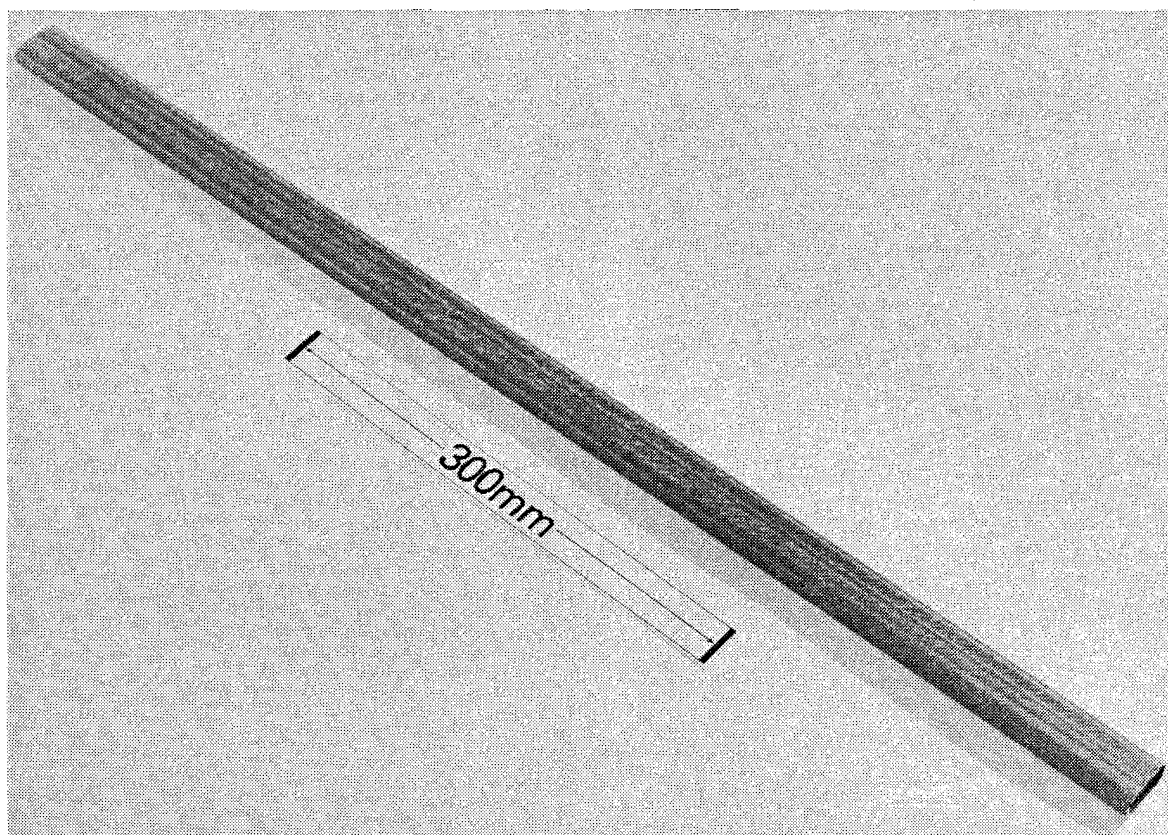


Figure 27. Prepreg Tunnel

BDX-613-2406

FABRICATION OF A KEVLAR LINER ASSEMBLY, A. H. Schloman, Topical, July 1980.

Several liner assemblies were fabricated with Kevlar 49 and epoxy using various wet layup and prepreg processes. A production process, using prepreg material, was developed for fabricating the liner and a wet layup molding process was used to fabricate the Kevlar hat-shaped tunnels. Fabrication of the tunnels using Kevlar prepreg with an autoclave curing process was evaluated.

PLASTICS: Processes

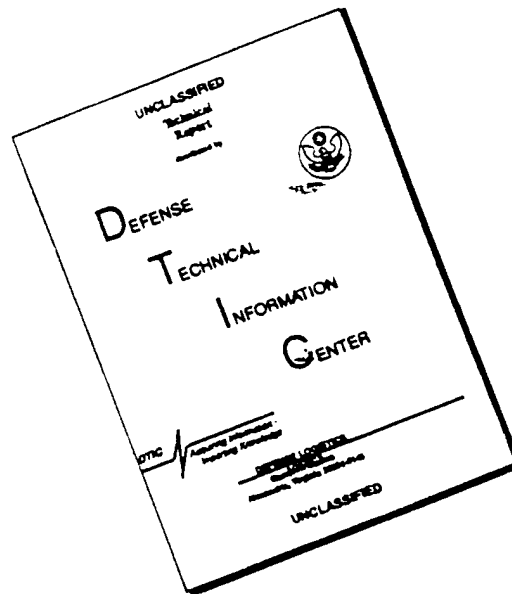
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